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ABSTRACT

The purpose of a study was to explore the link between conceptual understanding, free exploration of hands-on science center exhibits, and Piagetian cognitive developmental levels. In this primarily qualitative study, which is based upon interview and observational data, patterns in children's behavior relating to specific hands-on science center exhibits are described. The data gathering included selecting four exhibits, two that attempted to convey a concrete concept and two that presented a formal concept. Subjects were 45 children between the ages of 5 and 13. Each subject was interviewed and tested using a set of eight Piagetian tasks. The subjects were then divided into three categories: preconcrete, concrete, and postconcrete. After a pretest was given, each subject was given time for individual free exploration of an exhibit. After the subjects had completed as much exploration as they deemed necessary, they were asked to explain how they thought the exhibit worked. The answers of each subject were compared with a concept statement for each exhibit. The level of conceptual understanding of the concrete concept exhibits increased with each developmental group. All groups had difficulty understanding the exhibits requiring formal thought. (18 references) (KR)

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# THE EFFECTS OF FREE EXPLORATION FROM HANDS-ON SCIENCE CENTER EXHIBITS

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# THE EFFECTS OF FREE EXPLORATION FROM HANDS-ON SCIENCE CENTER EXHIBITS

## INTRODUCTION

Science literacy among the general public has become a topic of growing concern in recent years (National Science Board, 1983; Twentieth Century Fund, 1983; American Association for the Advancement of Science, 1982). The current trend toward virtual scientific and technological illiteracy--unless reversed--means that important national decisions involving science and technology will be made increasingly on the basis of ignorance and misunderstanding (National Science Foundation and U.S. Department of Education, 1980). Furthermore, we have entered an era of public participation in science that must be considered part of the "social cost of democracy" (Culliton, 1978). Over half the bills introduced in congress involved science or technology in some degree and the establishment of the standing Committee on Science and Technology in the House of Representatives attests to the importance of scientific and technological issues in the national political system (Miller, 1983). This lack of science literacy comes at an unfortunate time, since more decisions than ever before require at least a minimal level of science knowledge and understanding. The first director of the Museum of Science and Industry in Chicago complained that "the principles of science are not yet in the possession of the many, even though the age is essentially scientific" (Kaempffert, 1929). Since that time the situation has changed very little, although most citizens apparently want to educate themselves about complex scientific and technological issues in order "to make reasoned judgments about policy-related issues" (National Science Foundation, 1980).

Most of the learning that takes place in an individuals's lifetime occurs outside of the formal school setting. One study states that over 80% of the learning is not done in a traditional educational setting (Beer, 1984). Contemporary science and technology museums offer the public an opportunity to engage in informal science learning. Unlike school, the museum setting is voluntary, open-ended, nonlinear, hands-on, and entertaining. There are no requirements, no prerequisites, no exams, no grades, and social interaction is often an important part of the experience (Ucko, 1985).

The exhibits in contemporary science museums attempt to allow the visitor to experience science. After all, science literacy can be cultivated "only from concrete observational experience" and not through "verbal inculcation" for most individuals (Arons, 1983). Oppenheimer (1968) stated that "explaining science and technology without props can resemble an attempt to tell what it is like to swim without ever letting a person near water."

Most visitors are not attracted to science museums to learn facts; they come to explore new and interesting phenomena and to be entertained. However, at most science museums, there is no reason to be concerned that the visitors will leave feeling that they have not confronted enough facts. When individuals interact with an apparatus they gather a different kind of evidence than when they hear or read about something. The interactive visitor can manipulate objects, explore variables, and use the evidence obtained to reach a personal conclusion about the situation investigated (Thier & Linn, 1976).

Because of the large audiences, free-choice environments, and interactive exhibits, science centers are excellent laboratories for studying how people learn. The topics that can be fruitfully addressed in the science center laboratory range from questions that are particular to the museum enterprise itself, to general questions about learning (Feher & Diamond, 1990). Recent research ranges from the predominately descriptive to analysis of how specific features, such as display techniques or opportunity for hands-on interaction, affect visitor behavior. These studies have had surprisingly little impact on the development of exhibits and "no reliable general theories yet exist to predict how visitors will respond to exhibit features in a variety of museum settings" (McNamara, 1990).

The purpose of this research is to explore the link between conceptual understanding, free exploration of hands-on science center exhibits, and Piagetian cognitive developmental levels.

## SAMPLE

The subjects for this research were forty-five children between the ages of five and thirteen who were selected at random from a pool of possible subjects. Over 200 children responded to a published announcement requesting their help in evaluating museum programs and exhibits. This formed the pool of possible subjects. The sample is representative of the population of elementary school aged children that visit

a science museum. There are 26 girls and 19 boys included in the sample.

## DESIGN AND PROCEDURES

The results of a pilot study suggested that eight Piagetian tasks could provide enough information to classify each subject into one of three groups: pre-concrete, concrete, or post-concrete operational. The eight Piagetian tasks that were administered to each subject included: 1) conservation of number; 2) conservation of liquid amount; 3) conservation of solid amount; 4) conservation of area; 5) conservation of length; 6) conservation of volume; 7) equilibrium in the balance beam task (proportional reasoning); 8) colored beads task (combinatorial logic). The first five tasks were used to separate the pre-concrete subjects from the concrete operation subjects, while tasks six, seven and eight served to separate the concrete operational subjects from the post-concrete operational subjects. Subjects that did not conserve on two or more of the first five tasks were classified in the pre-concrete group as well as those that failed to conserve on one of the first five tasks and could not conserve on the volume task.

To qualify for the post-concrete group the subject had to be IIIA (early formal) on at least one of the last three tasks, (conservation of volume, balance beam and colored beads task) and be IIA (concrete) or IIB (late concrete/transitional) on the remaining two of the last three tasks. The subjects that did not qualify for the pre- or post-concrete operational groups were classified as concrete operational. Twelve subjects were classified as pre-concrete, 16 subjects as concrete, and 17 subjects as post-concrete.

The pilot study also provided background for preparing the research design regarding concept understanding. When asked a pretest question to assess their conceptual understanding of a formal concept presented by an exhibit, ninety-six percent of the subjects had no initial understanding of the concept. The pretest question also had no impact as an advance organizer. Based on the results of the pilot study it did not appear necessary to administer a pretest when subjects explored an exhibit that presented a formal concept.

For an exhibit which presented a concrete concept a pretest question was administered to half of the subjects, while the other half were not asked any pretest questions. The pretest question was asked verbally with each subject's response recorded on audio tape. Additional follow-up questions were asked to further explore the subjects'

conceptual knowledge. The questions were the same for subjects in all three groups.

After the pretest was completed, each subject was given time for individual free exploration of an exhibit. The exhibits included in this research are currently or have been on the main exhibit floor. All text that has been written for the exhibits remained and the written directions for use were the same ones provided for the public. The subjects received no assistance from anyone, except for those who could not read and the directions were read from the label if the child requested it. The experience of the subjects was to be strictly a free exploration. The instructions were to "play with the exhibit and find out all that you can about it."

After the subjects had completed as much exploration as they deemed necessary, they were asked to explain how they thought the exhibit worked. Additional questions were asked which followed-up on the children's answers to further explore their understanding of the concept presented by the exhibit. All of the post-test conversations were recorded on audio tape. This procedure was repeated for each exhibit used in this research.

The entire dialogue between each subject and the researcher was recorded on audio tape and transcribed. The answers of each subject were compared with a concept statement for each exhibit. Data from the pilot study indicated that the answers could be classified adequately into one of four categories: 1) complete understanding (answer closely matched the concept statement); 2) partial understanding (answer had some elements of the concept statement, but was not complete); 3) misconceptions (the answer contained conceptually incorrect statements); 4) no understanding (the subject stated they did not know the answer or the answer they gave had nothing to do with the exhibit). The classification of conceptual understanding into categories similar to these has been used in other research studies (Marek et. al., 1990; Marek and Bryant, 1991; Marek, 1986).

Preliminary analysis involved using descriptive statistical techniques. Percentages and frequencies were calculated to determine trends. A scoring system was used to evaluate the answers of the subjects. The scoring scale was: four points for a complete answer, three points for a partial answer, two points for a misconception, and one point for no understanding. Misconceptions were given more value than no understanding because the subject had to have some knowledge or experience on which to base their misconception. The misconception was often embedded in a

partial understanding answer. This allowed for a statistical comparison of answers among intellectual development groups for individual exhibits.

The five exhibits chosen for this research were the "Pipes of Pan", "Hot Air Balloon", "Body Resistance", "Bernoulli's Principle Airfoil Lift", and "Jacob's Ladder". The "Pipes of Pan" exhibit deals with the concept that longer tubes produce sounds that are lower in frequency when compared with shorter tubes of identical diameter and material. The "Hot Air Balloon" exhibit makes use of the concept that flames produce heat which heats the air above the flames, then rises into the balloon and eventually causes the balloon to rise. To understand the concepts for each of these exhibits requires the use of concrete thought.

The "Body Resistance", "Bernoulli's Principle Airfoil Lift" and "Jacob's Ladder" exhibits deal with concepts that require formal thought. The "Body Resistance" exhibit requires that the visitor touch each of two plates to determine what resistance his/her body has to the flow of electricity. A resistance gauge on the exhibit shows that the body has a natural resistance which is neither zero or infinity. "Jacob's Ladder" features a spark that is produced between two brass bars by a high voltage transformer when a visitor presses a button. The spark moves vertically between the bars until it reaches the top. At the top the spark forms an arrow point leading from the end of each bar to a higher point between the bars. The spark ionizes the air around it. This ionized air is less dense and provides a prefered path for the spark. As the less dense, ionized air rises, so does the spark. The "Bernoulli's Principle Airfoil Lift" exhibit makes use of the concept that air blowing past the airfoil produces lift. Air passing over the top of the air foil moves faster than the air below the air foil resulting in lower pressure above the air foil and upward movement.

## RESULTS FOR EXHIBITS REQUIRING CONCRETE THOUGHT

Pre-test questions relating to the "Pipes of Pan" and "Hot Air Balloon" exhibits were administered to half of the sample to determine if the pre-test questions acted as advance organizers. Data for both exhibits requiring concrete thought were analyzed with two-way ANOVAs, with main effects for the pretest and developmental level.

Pipes of Pan

The pre-concrete subject's interaction with the "Pipes of Pan" exhibit resulted with most of the subjects demonstrating partial or complete understanding of the concept that longer pipes produce lower sounds and shorter pipes produce higher sounds. For the concrete and post-concrete groups, all of the subjects demonstrated complete understanding of the concept. (See Table 1.)

Table 1
Percentages, Means and Standard Deviations for the Pipes of Pan Exhibit

| Group | N | Com[1] | Par.[2] | NU[3] | Mis[4] | Mean | Std |
|---|---|---|---|---|---|---|---|
| Pre-Concrete | 12 | 75.00 | 8.33 | 16.67 | 00.00 | 3.42 | 1.16 |
| Concrete | 16 | 100.00 | 00.00 | 00.00 | 00.00 | 4.00 | 0.00 |
| Post-Concrete | 17 | 100.00 | 00.00 | 00.00 | 00.00 | 4.00 | 0.00 |
| Overall | 45 | 93.33 | 2.22 | 4.45 | 00.00 | 3.84 | 0.62 |

NOTES: [1]Complete Understanding
[2]Partial Understanding
[3]No Understanding
[4]Misconceptions

The analysis of variance results (see Table 2) indicate significant main effects for both the presence of pretesting and for developmental level, as well as for the interaction between the two. A Ryan's test for individual comparisons revealed that both the concrete and post-concrete developmental groups had higher mean scores than the pre-concrete group.

Table 2
ANOVA for Pipes of Pan Exhibit

| Source | DF | SS | F | Prob |
|---|---|---|---|---|
| Pretest Given | 1 | 1.34 | 4.49 | 0.0405 |
| Developmental Level | 2 | 3.88 | 6.48 | 0.0037 |
| Pretest & Devel. Level | 2 | 2.40 | 4.02 | 0.0259 |
| Error | 39 | 11.66 | | |

The group that received the pretest actually had a lower mean score (3.71) than did the group that was not pretested (3.96). Inspection of cell means revealed that the pretest main effect and the interaction were confined to the pre-concrete group, as the subjects in the concrete and post-concrete groups all had scores of 4.0 regardless of whether or not they were pretested. However, in the pre-concrete developmental group, those who received the pretest had an average score of 2.80, while the mean for those who were not pretested was 3.86.

Hot Air Balloon

The "Hot Air Balloon" exhibit required concrete thought to understand the concept that fire produces heat, and then the heat rises and fills the balloon, causing it to rise. The majority of the concrete and post-concrete developmental groups attained complete understanding of the concept involved in this exhibit (see Table 3). However, fewer than half of the pre-concrete subjects achieved complete understanding, although over 80 percent left the exhibit with complete or partial understanding.

Table 3

Percentages, Means and Standard Deviations for the Hot Air Balloon Exhibit

| Group | N | Com[1] | Par.[2] | NU[3] | Mis[4] | Mean | Std |
|---|---|---|---|---|---|---|---|
| Pre-Concrete | 12 | 41.67 | 41.67 | 8.33 | 8.33 | 3.17 | 0.94 |
| Concrete | 16 | 87.50 | 12.50 | 00.00 | 00.00 | 3.87 | 0.34 |
| Post-Concrete | 17 | 100.00 | 00.00 | 00.00 | 00.00 | 4.00 | 0.00 |
| Overall | 45 | 80.00 | 15.56 | 2.22 | 2.22 | 3.73 | 0.62 |

NOTES: [1]Complete Understanding
[2]Partial Understanding
[3]No Understanding
[4]Misconceptions

As shown in Table 4, there was a significant difference among developmental levels on understanding of the concept taught by the "Hot Air Balloon" exhibit. Again, a Ryan's test for individual comparisons indicated that concrete and post-concrete groups had higher mean scores than did the pre-concrete group. There were no significant pretest or interaction effects.

Table 4

ANOVA for Hot Air Balloon Exhibit

| Source | DF | SS | F | Prob |
|---|---|---|---|---|
| Pretest Given | 1 | 0.00 | 0.02 | 0.8964 |
| Developmental Level | 2 | 5.65 | 10.04 | 0.0003 |
| Pretest & Devel. Level | 2 | 0.43 | 0.77 | 0.4710 |
| Error | 39 | 10.99 | | |

RESULTS FOR EXHIBITS REQUIRING FORMAL THOUGHT

Bernoulli's Principle

For the exhibit titled "Bernoulli's Principle," the majority of all subjects (regardless of developmental level) demonstrated no understanding or had misconceptions after they interacted with the exhibit. The entire concrete group

developed misconceptions. A small percentage of the post-concrete group developed complete or partial understanding.

Further discussion with the subjects demonstrating partial or complete understanding indicated that the exhibit had no influence in their understanding of "Bernoulli's principle." In fact, each of these subjects turned away from the exhibit when trying to explain "Bernoulli's principle," perhaps in an attempt to keep their current experience from interfering with some past knowledge they had acquired.

Table 5

Percentages, Means and Standard Deviations for the Bernoulli's Principle Exhibit

| Group | N | Com[1] | Par.[2] | NU[3] | Mis[4] | Mean | Std |
|---|---|---|---|---|---|---|---|
| Pre-Concrete | 12 | 00.00 | 00.00 | 41.67 | 58.33 | 1.58 | 0.51 |
| Concrete | 16 | 00.00 | 00.00 | 00.00 | 100.00 | 2.00 | 0.00 |
| Post-Concrete | 17 | 5.88 | 11.77 | 5.88 | 76.47 | 2.18 | 0.64 |
| Overall | 45 | 2.22 | 4.45 | 13.33 | 80.00 | 1.96 | 0.52 |

NOTES: [1]Complete Understanding
[2]Partial Understanding
[3]No Understanding
[4]Misconceptions

Analysis of variance with Ryan's individual comparison test revealed that pre-concrete subjects had the lowest mean understanding score. (See Table 6.)

Table 6

ANOVA for Bernoulli's Principle Exhibit

| Source | DF | SS | F | Prob |
|---|---|---|---|---|
| Developmental Level | 2 | 2.52 | 6.16 | 0.0047 |
| Error | 42 | 9.39 | | |
| Total | 44 | 11.91 | | |

Jacob's Ladder

For the "Jacob's Ladder" exhibit, all subjects developed misconceptions or demonstrated no understanding of the concept involved in the exhibit (see Table 7). The majority of each developmental group demonstrated misconceptions, while the rest indicated no understanding.

Table 7
Percentages, Means and Standard Deviations for the Jacob's Ladder Exhibit

| Group | N | Com[1] | Par.[2] | NU[3] | Mis[4] | Mean | Std |
|---|---|---|---|---|---|---|---|
| Pre-Concrete | 12 | 00.00 | 00.00 | 33.33 | 66.67 | 1.87 | 0.34 |
| Concrete | 16 | 00.00 | 00.00 | 12.50 | 87.50 | 1.67 | 0.49 |
| Post-Concrete | 17 | 00.00 | 00.00 | 41.18 | 58.82 | 1.59 | 0.51 |
| Overall | 45 | 00.00 | 00.00 | 28.89 | 71.11 | 1.71 | 0.46 |

NOTES: [1]Complete Understanding
[2]Partial Understanding
[3]No Understanding
[4]Misconceptions

The no understanding percentages for the pre-concrete and post-concrete groups were much higher than for the concrete groups because more of the subjects in these two groups were willing to admit they really did not understand the concept behind the exhibit. The concrete subjects would attempt to develop an explanation which was usually classified as a misconception. The analysis of variance results (see Table 8) revealed no significant differences among the developmental levels on understanding scores.

Table 8
ANOVA for Jacob's Ladder Exhibit

| Source | DF | SS | F | Prob |
|---|---|---|---|---|
| Developmental Level | 2 | 0.71 | 1.63 | 0.2095 |
| Error | 42 | 8.53 | | |
| Total | 44 | 9.24 | | |

Body Resistance

For the "Body Resistance" exhibit none of the subjects demonstrated complete understanding, however a small percentage of the concrete and post-concrete groups demonstrated partial understanding. Again the concrete group had the highest percentage of subjects developing misconceptions. (See Table 9.)

Table 9
Percentages, Means and Standard Deviations for the Body Resistance Exhibit

| Group | N | Com[1] | Par.[2] | NU[3] | Mis[4] | Mean | Std |
|---|---|---|---|---|---|---|---|
| Pre-Concrete | 12 | 00.00 | 00.00 | 50.00 | 50.00 | 1.50 | 0.52 |
| Concrete | 16 | 00.00 | 12.50 | 6.25 | 81.25 | 2.06 | 0.44 |
| Post-Concrete | 17 | 00.00 | 17.65 | 23.53 | 58.82 | 1.94 | 0.66 |
| Overall | 45 | 00.00 | 11.11 | 24.44 | 64.45 | 1.87 | 0.59 |

NOTES: [1]Complete Understanding
[2]Partial Understanding
[3]No Understanding
[4]Misconceptions

There were significant differences among the group's mean understanding scores (see Table 10). The concrete and post-concrete groups had higher means than did the pre-concrete developmental group.

Table 10
ANOVA for Body Resistance Exhibit

| Source | DF | SS | F | Prob |
|---|---|---|---|---|
| Developmental Level | 2 | 2.32 | 3.72 | 0.0332 |
| Error | 42 | 12.88 | | |
| Total | 44 | 15.20 | | |

COMPARISON OF EXHIBITS REQUIRING CONCRETE OR FORMAL THOUGHT

Table 11 displays the outcome of subject's interactions with exhibits requiring concrete thought compared to those requiring formal thought. Nearly 90 percent of the interactions with exhibits requiring concrete operational reasoning resulted in complete understanding, in contrast to fewer than one percent of the interactions with exhibits requiring formal thought. Indeed, the majority of interactions with exhibits requiring formal thought resulted in misconceptions.

Table 11
Overall Percentages for Exhibits Requiring Concrete and Formal Thought

| Exhibits | N | Complete[1] | Partial[2] | No Und.[3] | Misconceptions[4] |
|---|---|---|---|---|---|
| Concrete | 90 | 86.87 | 8.89 | 3.33 | 1.11 |
| Formal | 135 | 0.74 | 5.19 | 22.22 | 71.85 |

NOTES: [1]Complete Understanding
[2]Partial Understanding
[3]No Understanding
[4]Misconceptions

A difference score was computed by subtracting each subject's mean understanding score for exhibits requiring formal thought from his/her mean score for exhibits requiring concrete operational reasoning. A one-sample t-test was then computed, which indicated a significant difference between the overall understanding of concrete and formal concepts. (See Table 12.) There were no significant differences among developmental levels on this computed score. When the mean difference scores for the groups were compared the differences between groups were small enough so that no statistically significant differences were found.

Table 12
Means, Standard Deviations, and t-test results for the Difference between Exhibits Requiring Concrete and Formal Thought

| | N | Mean | Std. | t | prob |
|---|---|---|---|---|---|
| Concrete | 45 | 3.78 | 0.58 | | |
| Formal | 45 | 1.84 | 0.32 | | |
| Difference | 45 | 1.94 | 0.65 | 20.06 | 0.0001 |

## DISCUSSION AND IMPLICATIONS

The level of conceptual understanding on the exhibits requiring concrete thought increased with each developmental group. The pre-operational subjects demonstrated the least understanding while the post-concrete group had the highest level of understanding. This finding is consistent with Piagetian developmental theory. Each subject in the pre-concrete group was placed in that group because he/she was pre-operational on at least one or more of the conservation tasks. This lack of conservation (pre-operational thinking) may have contributed to their demonstrating less understanding of the exhibits requiring concrete thought than did the other developmental groups.

For the exhibits requiring formal thought to understand the concept, all groups of subjects had difficulty developing conceptual understanding. The results indicate that museum visitors who are incapable of using formal thought will develop no understanding or acquire misconceptions from an exhibit that requires formal thought. There were a few subjects who developed partial or complete understanding for two of the three exhibits requiring formal thought. The exhibits were "Bernoulli's Principle" and "Body Resistance." It is possible that some of this could be due to prior knowledge. A subject who had extensive experience with airplanes would have a greater chance of

demonstrating at least partial understanding of the concept. Airplanes are not an uncommon interest of the curious upper elementary school student. The "Body Resistance" exhibit also uses some knowledge that an upper elementary school student could obtain from experience with electricity and circuits. However, very few upper elementary school students would have experience working with high voltage sparks. This may explain why no subjects in this study had partial or complete understanding of the concept from the "Jacob's Ladder" exhibit. This could also explain why this exhibit had the highest percentage of no understanding.

For museums, exhibit planners must decide if they are trying to deliver conceptual understanding to elementary school children and others using concrete thought. If this is a goal, then exhibits will have to be designed with the learner taken into consideration. This does not mean that exhibits should provide conceptual understanding only on the concrete reasoning level, but at least some aspect of the exhibit should provide for conceptual understanding on that level.

Many schools plan field trips to science museums under the guise of them being educational experiences. A brief inventory of the concepts presented by the exhibits can tell the teacher whether the children will have the opportunity to develop conceptual understanding or misconceptions. If the exhibits require formal thought to understand the concepts, elementary school children will either have no conceptual understanding or they will develop misconceptions.

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